Journal of Cleaner Production 57 (2013) 228–237

Contents lists available at SciVerse ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Resilience to evolving drinking water contamination risks: a human error prevention perspective

Yanhong Tang [a], Shaomin Wu [b], Xin Miao [a,*], Simon J.T. Pollard [c], Steve E. Hrudey [d]

[a] School of Management, Harbin Institute of Technology, Harbin 150001, PR China
[b] Kent Business School, University of Kent, Canterbury CT2 7PE, UK
[c] School of Applied Sciences, Cranfield University, Bedfordshire MK43 0AL, UK
[d] Environmental Toxicology Division, Faculty of Medicine & Dentistry, University of Alberta, Edmonton T6G 2G3, Canada

A R T I C L E I N F O

Article history:
Received 3 March 2013
Received in revised form
8 June 2013
Accepted 11 June 2013
Available online 21 June 2013

Keywords:
Drinking water incident
Contamination
Human error
Resilience
Risk management

A B S T R A C T

Human error contributes to one of the major causes of the prevalence of drinking water contamination incidents. It has, however, attracted insufficient attention in the cleaner production management community. This paper analyzes human error appearing in each stage of the gestation of 40 drinking water incidents and their causes, proposes resilience-based mechanisms and tools within three groups: consumers, drinking water companies, and policy regulators. The mechanism analysis involves concepts and ideas from behavioral science, organizational culture, and incentive analysis. Determinants for realizing cleaner drinking water system are identified. Future efforts and direction for embedding resilience into drinking water risk management are suggested. This paper contributes to identifying a framework and determinants of resilience-oriented management mechanisms for cleaner drinking water supply, and, is essential for ensuring the successful practice of managing drinking water contamination risks. It harmonizes the two fields of risk management and resilience thinking, and provides a new insight for implementing effective actions in drinking water-related sectors.

1. Introduction

The drinking water utility is a typical sector that needs cleaner production. Providing wholesome, affordable and safe drinking water that has the trust of customers should be the overarching goal of the drinking water utility sector (AWWA et al., 2001; IWA, 2004). Therefore, drinking water utility sector is special in need of cleaner production. Interruption of water supply or deterioration of drinking water quality often leads to immense negative impact on people's daily living (Jalba et al., 2010). Risk management for safe drinking water is receiving increasing attention partly because drinking water disease outbreaks have been causing serious losses. Chang et al. (2012) pointed out that drinking water utilities are inherently vulnerable to contamination incidents caused by routine operations, and accordingly, proposed to develop modern concepts and approaches to risk management for these utilities. The experience of the past few decades has shown that it is not enough to merely rely on treated water compliance monitoring to ensure safe drinking water. The water sector is experiencing a significant shift in the approach from ad hoc approaches to one that increasingly manages risk explicitly and broadly (MacGillivray et al., 2007). "Process optimization, monitoring, training and management combined with improved governmental policies" (Klemeš et al., 2012) are critical contributors to clean production of drinking water.

Many papers have pay attention to cleaner production from various perspectives; however, seldom is seen to consider this aspect from human error prevention perspective. Human error plays a significant role in contributing to drinking water contamination incidents. A thorough analysis of human error in various stages of drinking water contamination incidents could be beneficial in preventing further outbreaks and ensuring cleaner drinking water supply. Here we attempt to discover potential causes of human errors in each stage of the gestation of drinking water contamination incidents and explore the potential multidimensional approaches for coping with human errors to improve the resilience of drinking water systems.

The term *resilience* serves as a right overarching concept to represent the idea of managing risks through prevention, reduction and mitigation. This notion includes how individuals and organizations adapt to and act on risks (Beermann, 2011). The Oxford English Dictionary defines *resilience* as the capacity of returning or

* Corresponding author.
E-mail addresses: miaoxin@hit.edu.cn, xin.miao@aliyun.com (X. Miao).

0959-6526/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jclepro.2013.06.018

springing back. This means in a physical sense that a system or an object can resume its initial stage or state after being displaced. *Resilience* is also defined as elasticity (Blackmore and Plant, 2008), and it has been referred to the art of managing unexpected, or how a team or organizations becomes prepare to cope with surprises (Attoh-Okine, 2009).

2. Methodology

The breakout of a drinking water contamination incident may be seen as a result of accumulation of risks from unsafe factors in a drinking water utility sector. Heinrich (1959) put forward the famous causal chain theory to explain the occurrence of an accident, which could only occur in a moment but is a consequence of a series of causalities of various factors that had occurred. Heinrich conducted a survey on 75,000 industrial accidents. The survey result showed that only 2% of these accidents cannot be prevented, and the remaining 98% can be prevented or avoid. For that 98% of all accidents, unsafe human actions accounted for the majority, that is, 88%, and unsafe states of materials accounted for only 10%. Furthermore, the insecurity of materials was largely caused by unsafe human actions. Therefore, Heinrich concluded that almost all accidents were caused by unsafe human actions.

Unsafe human actions were considered as human errors in Reason's research (Reason, 2000). The famous Swiss cheese model put forward by Reason can be understood from organization management perspective. Organizational behavior plays a critical role in the risk evolution of an accident. Organization management can serve as firewalls in the risk evolution process of an accident; however, there are different degrees of vulnerability in organization management. The emergence of dynamic loopholes in the barriers formed by organization management will permit accident risks penetrating through these loopholes, especially various regulatory loopholes overlap in which risks of accidents are more likely to evolve rapidly into real emergencies. In other words, advanced organization management can serve as barriers to block risk evolution, while poor organization management will serve as booster to accelerate risk evolution. Understanding human error from organization management perspective provides significant opportunities for improving safety and promoting cleaner production for drinking water utility sector.

Based on a secondary analysis of 62 drinking water incidents occurring in affluent countries between 1974 and 2001 reported by Hrudey and Hrudey (2004), Wu et al. (2009) found that in 78% of the 62 water incidents, human errors were direct or indirect contributors. This finding suggested "investigation of the lifecycle of drinking water incidents" as one of the pertinent areas for future research. That is, understanding the distribution of human errors across the lifecycle of drinking water incidents might help identify opportunities to reduce human errors and provide a deeper insight into their gestation.

Wu et al. (2009) suggested that the gestation of a typical water incident might cover 6 periods: contamination, sensing, warning, recognition, inspection and recovery (Fig. 1). Analyzing human error in each period is helpful because the identification of common human errors may significantly contribute to the purposeful design of effective countermeasures. A root cause analysis may also contribute to the early discovery and reduction of potential hazards, and accordingly, reduce risks.

For risk evolution of drinking water contamination incidents, resilience may be considered from two perspectives, that is, how to avoid the occurrence of an incident, and how to quickly and efficiently respond to the incident, to minimize losses and social impacts it causes. Resilience can be enhanced by both risk reduction activities undertaken before an incident and response activities following the incident (McDaniels et al., 2008).

Human error cannot be eradicated completely because of its unpredictability and uncertainty related with human behavior. However, it is possible to reduce the probability of occurrence and the adverse consequences when it does inevitably arise (Reason, 2000). This can be achieved by improving the process of drinking water risk management to "make it hard for people to do the wrong thing and easy for people to do the right thing" (Kohn et al., 2000), and to quickly recognize unfavorable situations within the water supply system and promote its return to effective performance.

This paper completes the analysis of Wu et al. (2009) through investigating 40 cases of drinking water contamination incidents by content analysis to identify typical human errors and their distributions in each period of the evolution process, proposing countermeasures to their root causes, and put forward strategies from organization management perspective for building resilience in the process management of risk evolution of drinking water contamination incidents.

3. Material and methods

Below, using content analysis, we reinvestigate 33 cases of drinking water incidents from Hrudey's primary analysis (Hrudey et al., 2003; Hrudey and Hrudey, 2004; Hrudey et al., 2006; Hrudey and Hrudey, 2007), and examine further 7 cases collected from other sources (Table 1).

Although we reviewed and scrutinized more than one hundred water incidents, only these 40 cases were finally chosen for analysis considering the typicality and influence of these outbreaks and incidents. Moreover, although some cases are influential, but there is insufficient official reports about the evolutive details of each stage corresponding to the typical gestation model (Wu et al., 2009), which will result in inaccuracy in distinguishing each stage shown in Fig. 1. So we abandoned those cases without sufficient information in terms of the evolutive details to minimize potential author bias.

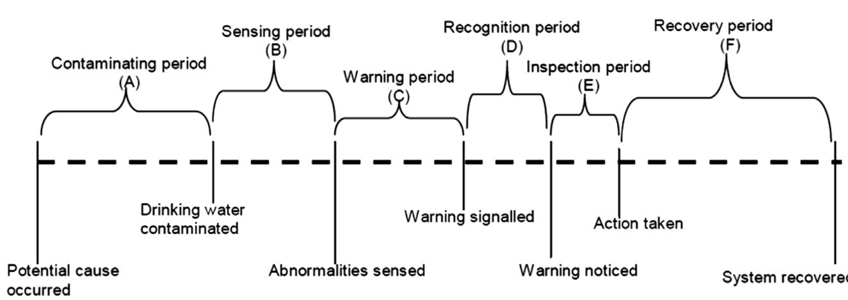

Fig. 1. A typical gestation for a drinking water incident (adapted from Wu et al. (2009)).